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BLANKING BY MEANS OF THE FINITE ELEMENT METHOD

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Abstract. *This paper summarizes the results of simulating the blanking process by means of the Finite Element Method. Unlike most of the research in this field, the focus is not on the blanking process itself but on the deformed shape of a product after blanking. Two ways of determining the shape of a product after blanking are investigated. One way is to calculate the internal stresses caused by the blanking process and relax these stresses to calculate the new shape. The internal stresses can be transfered into an equivalent load model that can characterize the blanking process. With this equivalent load model the deformed shape of a product after blanking can be determined in a very fast and easy way. Experiments are done to verify the results. Both introduced methods give qualitatively good results. Also some suggestions for improvements are made.*

1 INTRODUCTION

Blanking, shearing and slitting are widely used sheet metal forming processes. In the production of discrete sheet products, the blanks are cut out of large sheets by a shearing process. The blanks are formed in different steps to semi–finished products with processes like deep-drawing and bending. Next the surplus material has to be removed from the edges of the product or holes have to be stamped in the product. Currently these processes are mainly based on experiments. Analytical models are available[1] but are unable to represent all the phenomena involved. Although irregularities such as bow, twist and camber of sheet material after blanking, shearing or slitting is a well–known aspect of sheet metal forming,[2] it is not investigated often. In most of the publications only the blanking process itself is analyzed or they focus on one of the problems of the process itself: simulating the profile of the cut edge, predicting the process forces or predict the ductile fracture. Only in case of slitting or guillotining the deviation of the shape received some attention.[2] However, shearing and blanking are often followed by other manufacturing processes and the dimensional product tolerances are becoming more strict too. Knowledge of the effect of shearing and blanking on the product shape will be increasingly important. Therefore it is important to know the influence of the shearing process on the product. Hence, this research is started to gain more insight in cutting processes like blanking, shearing or slitting. This paper will show two different approaches to determine the flatness of a product after blanking. The calculations in this paper are done with the Finite Element program DiekA.

1.1 Different approaches

The first approach to determine the flatness of a sheet after blanking is to calculate the internal stresses in the sheet introduced by blanking by a detailed FEM analysis. Because DiekA is not able to simulate ductile fracture yet, another procedure is used to calculate the residual stresses. The blanking process is modeled without a ductile fracture model. The simulation of the blanking process is stopped when fracture would occur. Then the material stiffness and strength of the part that is cut off are set to zero. The stresses that remain in the sheet are the internal stresses due to the blanking process. These stresses can be transferred into the Finite Element model of the sheet. In this way the deformed shape of the sheet after blanking is predicted.

The second approach to determine the flatness of a cut product is based on experiments. For the experiments a rectangular sheet is used in which a number of holes is punched. The flatness of the sheet is measured before and after the blanking process. The difference is a result of the internal stresses in the sheet caused by this process. A simple equivalent load model is developed, which simulates the effect of the internal stresses. The parameters of this model are deduced from a fit between the results of FEM calculations with this model and the experiments. This simple model should be equivalent to the stresses that are calculated in the first method. With this equivalent load model, FEM calculations are done to fit to the experiments. This simple method will give fast insight into the final shape and flatness of the sheet after it has been cut.

2 MODELING THE BLANKING PROCESS BY FEM

As mentioned before the blanking process is one of the most common forming processes in sheet metal forming. The position of the blanked contour as well as the geometry of the cut edge can effect the product quality seriously. Accurate components are needed in larger and larger quantities and at the same time they must cost less to produce. FEM simulations are increasingly used in order to investigate and optimize this process. However, the numerical approach for studying blanking is still in a tentative stage. Blanking is a shearing operation which involves elastic and plastic deformation, damage and fracture and many other non linearities.[3] Modeling ductile fracture with FEM is one of the main difficulties in the blanking process. Most simulations of blanking or shearing include a damage model[4] which is combined with a continuous re-meshing procedure[5,6] to simulate fracture. Lately some work has been done on modeling the ductile failure by an elastoplastic plastic damage model for large deformations.[3] Another method to describe the ductile failure is to kill the elements which exceed a certain criterion.[7,8] Simulating shearing or blanking gives also some other problems. Since it is a process with very high local deformation, only a FEM program which is capable of dealing with large deformations can be used. The DiekA program is such a program because it is a Mixed Eulerian Lagrangian code (ALE–method).[9] However in blanking the geometry changes are so large that the ALE-method alone does not suffice in keeping the mesh regular enough. An improvement is found when the ALE–method is combined with remeshing, as was shown by Brokken.[10] However, to simulate the whole process, a ductile fracture model is needed as well. Such a model is not incorporated in DiekA yet. Meanwhile a different method is chosen in order to calculate the residual stresses, because the form of the cut edge is not important.

2.1 Residual stresses

As said before the calculations are done with DiekA. This program is capable of performing calculations with an Updated Lagrangian formulation as well as an ALE formulation which combines the positive aspects of the Eulerian method and the Updated Lagrangian method. With this method the mesh deformation and the material deformations are decoupled.[9] Figure 1 shows an axi–symmetric two dimensional blanking process. The sheet is clamped between the die and the die plate. Then the punch is forced down. Initial there are no cracks present but after the punch has penetrated into the material high tensile stresses and high strains develop near the punch and die edges. A crack will be initiated which will finally separate the sheet. Because DiekA includes no ductile fracture criterion it is not possible to simulate the actual separation. In order to calculate the residual stresses in the workpiece without simulating the final separation by fracture, the following procedure is used: The calculation is ended when the punch has penetrated

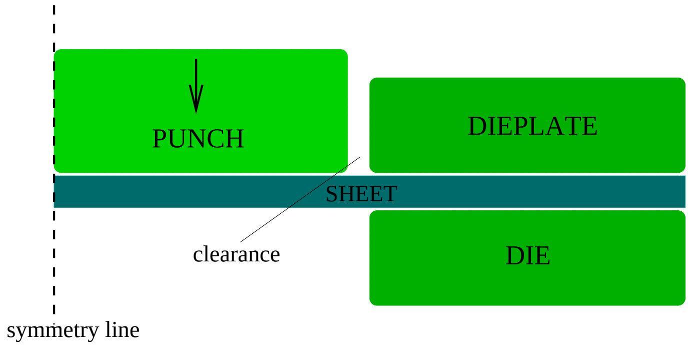
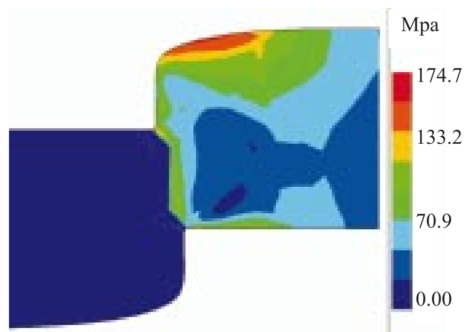


Figure 1: The axi–symmetrical blanking process

(a) Von Mises stress after halfway penetration of material



(b) Von Mises stress with E and σ_{yield} down

Figure 2: Diminishing the influence of the part that is cut off

the material halfway. From this moment crack initiation would have been very likely. The sheet is still clamped between the die and die plate and no separation has occurred (see Figure 2.a). In order to calculate the internal stresses as if separation would have occurred, the Young's modulus and the yield stress are reduced to zero. In that case the part that remains does not 'feel' the influence of the material that would be cut off any more (Figure 2.b). At this point the stresses that remain will cause deflection of the sheet after the die plate will be removed. However for the moment, the workpiece is clamped and the present stress values are saved for transferring into the integration points of a FEM model of the total workpiece (see Figure 3). In this figure only a quarter of a 3D sheet with one hole punched in it is shown.

2.2 Example

A rectangular sheet is simulated in which a number of holes is punched. The dimensions of the sheet are 100 mm * 100 mm and the hole has a diameter of 22 mm. The sheet

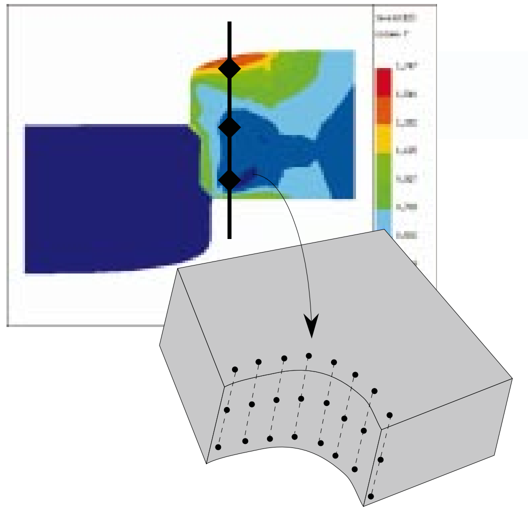


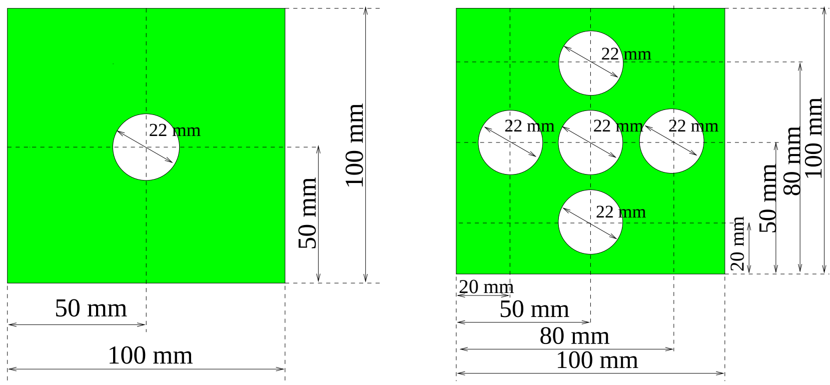
Figure 3: Transferring stresses from local into global calculations

has a thickness of 1 mm. The number of holes (one or five holes) in the sheet is varied (see Figure 4; Geometry of the sheets) as well as the material of the sheet (aluminum or stainless steel see table 1).

	Aluminum (AA5754)	Stainless Steel (AISI 316)
Modulus of elasticity (E)	70000 MPa	203330 MPa
Poisson's ratio (ν)	0.33	0.3
ultimate tensile strength (UTS)	220-260 MPa	500-700 MPa
Yield stress ($\sigma_{0.2}$)	130 MPa	240 MPa

Table 1: The material parameters

An axi–symmetric calculation of the blanking process is carried out with a clearance of 15 %. The punch has a radius of 0.01 mm. The calculation is stopped when the punch has penetrated about half the material. Then the material parameters (E and σ_{yield}) of the cut off part are reduced to zero. At this time the sheet is still under the die and the die plate. When the die plate is removed, the relaxation of the internal stresses will cause springback of the sheet. This springback will cause a deflection of the sheet. The large plastic deformation is highly concentrated near the cut edge and it is assumed that this does not effect the elastic springback of the sheet. The stresses are transferred and put into the whole 3D sheet. The 3D sheet is simulated with Kirchoff elements. These plate elements have three integration points in the plane and 7 integration points in the thickness direction. Because the sheets are symmetrical only a quarter of the sheet is simulated. After the elastic springback the deflection of the sheet due to the blanking



(a) Sheet with one hole (b) Sheet with five holes

Figure 4: Geometry of the sheets

(a) One hole (b) Five holes

Figure 5: Deflection of the sheet after relaxation of the internal stresses

process can be calculated. Figure 5.a shows the whole sheet with one hole and Figure 5.b shows the whole sheet with 5 holes. Notice that the deflection in these figures is very exaggerated. Figure 7 shows the calculated and the measured deflection of the sheet with one hole. In these figures a cross–section of one half of the sheet can be seen (see Figure 6). On the x axis the coordinate in the sheet is plotted, starting at zero in the middle of the sheet and on the y axis the deflection of the sheet is plotted. Four points were measured over half the sheet width (for each of the four directions). A straight line is drawn between these points. The experiments are explained in more detail in Chapter 3. The experiments and the FEM calculations show a good agreement. For a better validation of the calculated deflections near the cut edge, more local measurements are needed. It is also found that the elastic material properties have a great influence on the deflection of the sheet. The elastic material properties are very hard to determine because the preceding forming processes are unknown and the material properties depend on these processes.

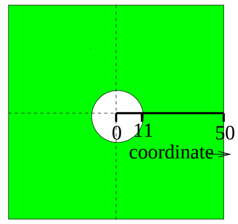
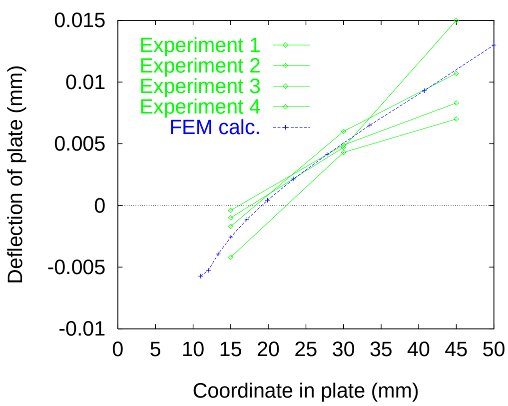
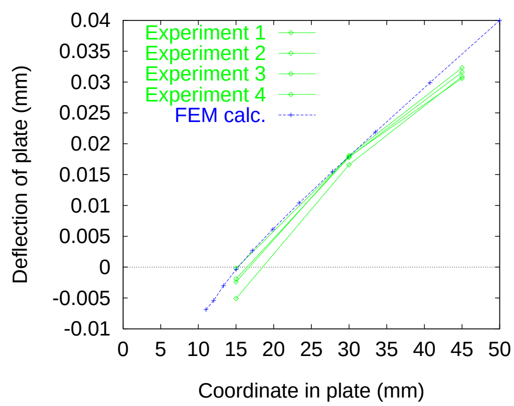


Figure 6: Coordinate in sheet



(a) Aluminum sheet with clearance 15%



(b) Steel sheet with clearance 15%

Figure 7: Experiments and FEM calculation with internal stresses for sheet with one hole

3 EXPERIMENTS AND LOAD MODEL

The second approach for determining the shape after blanking is based on experiments. With the results of the experiments an equivalent load model can be constructed. These experiments serve also for the validation of the more theoretically based first method as was shown in Figure 7. The most important idea is to develop a simple method to predict the final shape of a product after shearing (stamping, slitting or blanking). This will give opportunities to develop a blanking system with optimal results with regard to accuracy and flatness.

3.1 Experiments

The experiments are done with the same sheet geometry: 100 mm * 100 mm with a thickness of 1 mm and number of holes of 22 mm in diameter is punched in the sheet (see Figure 4). Two experiments are shown, one with one hole punched in the center and one with 5 holes punched in the sheet. The experiments are done with two different types of material (see table 1). The holes are punched with a standard punch unit, a Wales Strip pit Contimec 25 BL 260. This unit is placed in a press. Different clearances are obtained by using blanking dies of a slightly different diameter (22.15 mm and 22.30 mm). To be certain that only the deflection due to the blanking process is measured, the shape of the sheets before and after the blanking process is measured. Because the deformations are relatively small, an accurate shape measuring device is needed. The measurements of the geometry are performed with a 3D co–ordinate machine (Zeiss UMC 550 S) with a mechanical sensor which exerted a contact force of 0.05 N. In order to eliminate systematical errors, the specimens were measured before and after punching with the same alignment in the machine. However, test measurements with different alignments of the same specimen showed a good reproducibility of the results.

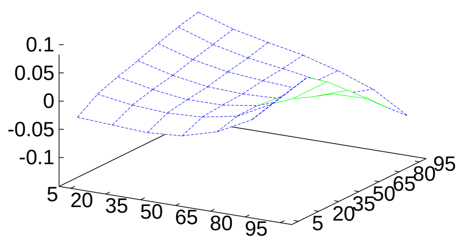
In Figure 8 the measurements of the sheet with 5 holes and a clearance of 7.5% can be seen. Measured were the positions of a grid of reference points on the workpiece.[11]

The three figures on the left denote the experiments done with an aluminum sheet and the figures on the right denote the experiments with the stainless steel. It is important to measure the shape of the sheet before blanking because the sheet has already a lot of internal stresses due to the processes that were preceded by the blanking process (rolling and cutting out the sheet for example). Therefore the shape of the sheet after punching is decreased with the shape before punching. In Figure 8.a and Figure 8.b the sheet before blanking is seen. In both cases the sheets are not plain. In case of the aluminum sheet the edge of the sheet at one side is very deformed. This deformation stays in the sheet even after blanking (see Figure 8.c). In Figures 8.e and 8.f the geometry after blanking is decreased with the geometry before blanking. In case of the aluminum where a very twisted sheet was seen, nothing of the twist remains. In both cases a kind of cup is the remaining deflection. This deflection is an indication for the forces applied on the sheet. The force that is needed to produce such a cup is possible a torque around the hole that is punched.

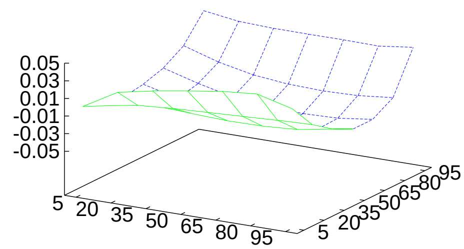
The experiments are done with different clearances for both materials. The clearances that are used are 7.5% and 15%. These results can be seen in Figure 9. For the aluminum as well as for the steel the differences in clearance are minimal. The variation of the experiments with both clearance is too large. To be able to see more difference of the clearance on the deflection of the sheet more data points near to the cut edge should be measured.

3.2 Load model

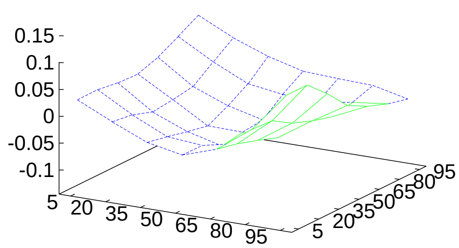
A simple load model is developed, which simulates the effect of the internal stresses. The parameters of this model are deduced from a fit between the results of the FEM calculations with this model and the experiments. This simple method will give fast insight in the final shape and flatness of the product as it has been cut. This equivalent load model is possibly a torque over the cutting edge, because the experiments show a



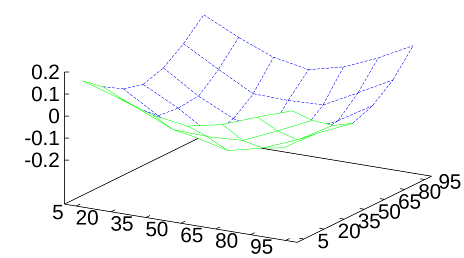
(a) Shape of an aluminum specimen before blanking



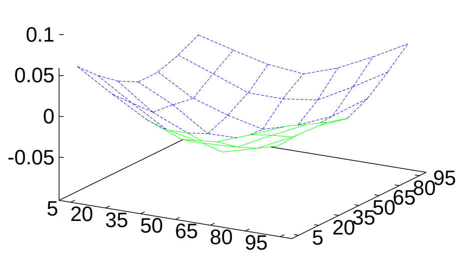
(b) Shape of a steel specimen before blanking



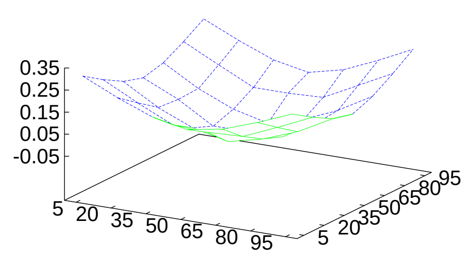
(c) Shape of an aluminum specimen after blanking



(d) Shape of a steel specimen after blanking

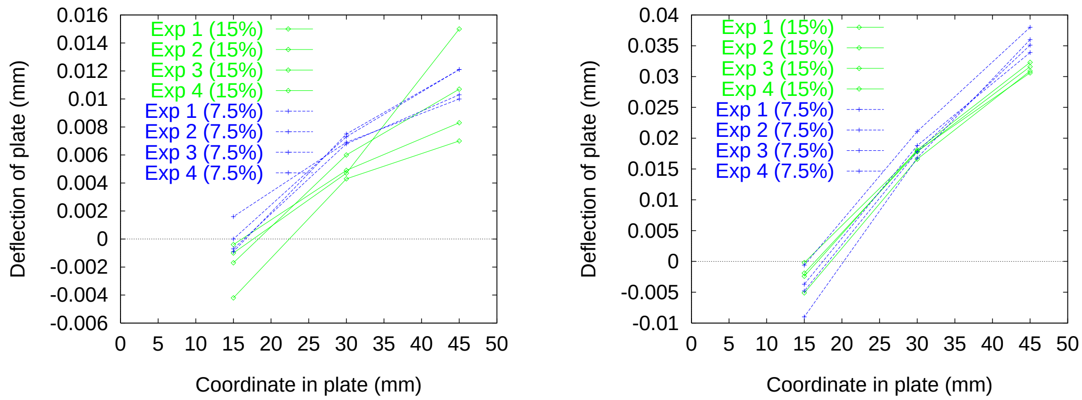


(e) Deflection of an aluminum specimen; difference between a and c



(f) Deflection of a steel specimen; difference between b and d

Figure 8: Experiments for sheet with 5 holes and a clearance of 7.5 %



(a) Aluminum sheet with clearance of 7.5% and 15%

(b) Steel sheet with clearance of 7.5% and 15%

Figure 9: Experiments with different clearances

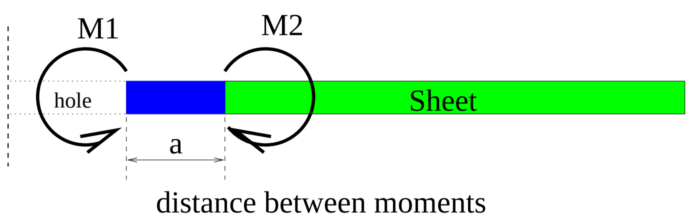
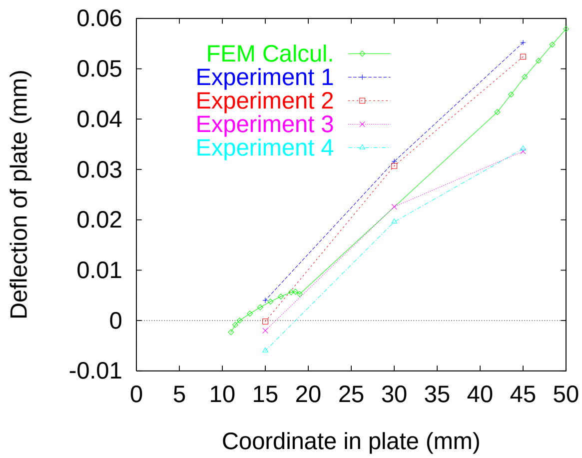
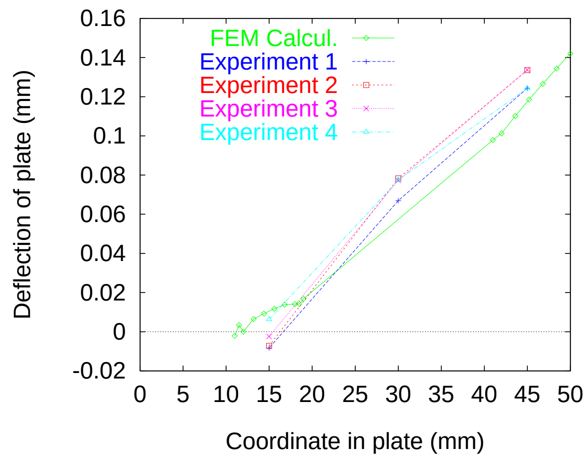


Figure 10: Equivalent load model with two torques; cross–section of half the sheet (axi–symmetrical)

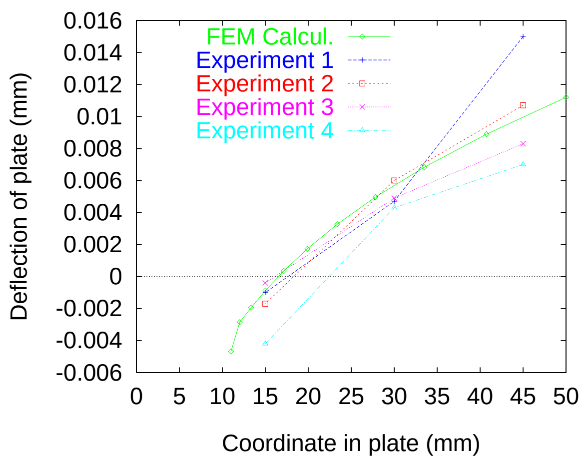
cup after blanking. In this case where the cutting contour is closed one moment could be enough, but in a case of an open contour, one moment would not give equilibrium. Hence, a two moment model is chosen with a certain distance a between the moments $M1$ and $M2$ in the sheet (see Figure 10). This distance a can help to characterize the cutting parameters like the clearance between the punch and die or the plastic zone. The stresses of the blanking process have only influence in one or two times the sheet thickness so an one moment model would not be appropriate because the stresses are smeared out over the whole sheet and additional forces are needed to give equilibrium. For the distance between the two moments the width of the plastic zone is chosen. With this two moment model new FEM calculations are carried out. Figure 11 shows the results of the calculations with the simple load model. Again a cross–section of one half of the sheet width can be seen (see also Figure 6). On the x axis the coordinate in the sheet is plotted and on the y axis the deflection of the sheet. Again four points were measured over half the sheet width. A straight line is drawn between these points. In case of the sheet with 5 holes the center of the second hole on the x axis lies on the coordinate 30 mm. In case of the sheet with 5 holes the experiments and the calculations give good agreement. Between the coordinate point 11 and 20 the calculations show a curve. In the experiments only



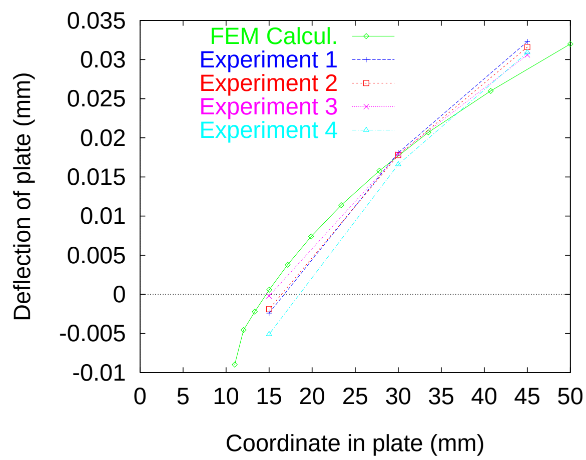
(a) Aluminum sheet with 5 holes and clearance 15%



(b) Steel sheet with 5 holes and clearance 15%



(c) Aluminum sheet with 1 hole and clearance 15%



(d) Steel sheet with 1 hole and clearance 15%

Figure 11: Verification of calculations with load model and experiments

one point is measured in this region so no curve can be seen. In case of the sheet with one hole the sheet has an overall curve. Especially in the region near the hole the curve is strong. The experiments can only show an indication of the deflection of the sheet and can not show an overall curve. In case of five holes both materials show more deflection than in case of one hole. In both cases the deflection of the steel sheet exceeds the one for aluminum. The FEM calculations and the experiments give good agreement but to be able to give a better conclusion about the constructed equivalent load model more points should be measured especially near the cut edge.

4 CONCLUSIONS

It is possible to predict the shape of a product after it has been cut by blanking. Two methods are introduced: one based on experiments and the other based on the calculated internal stresses of the blanking process. Both methods give qualitatively good results. However, to be able to give more detailed conclusions more data of the experiments have to be known. Especially near to the cut edge where strong curves can be seen in the calculations.

To be able to determine the shape more precisely, the magnitudes of the internal stresses have to be calculated more accurate. So it is necessary to implement a fracture criterion in the FEM model so that the FEM model will yield to better internal stresses.

Because very large geometrical changes take place in the blanking process, the ALE method solely is not enough to keep the mesh regular. For blanking the ALE method should be combined with a remeshing technique.

The springback of the material is an elastic process. The elastic modulus is a material parameter which is assumed to be constant. Experiments of Chakhari and Jalinier demonstrate that the elastic modulus is not a constant but varies with the plastic deformation which can cause a decrease up to 16 %. The elastic modulus is also dependent on the rolling direction due to the developed textures. This can cause an increase of 1-10 %.[12] Because the elastic modulus is a very important parameter in the elastic springback, these differences can cause large differences in the deflection of the sheet. To be able to get quantitatively good results the material parameters should be known more precisely.

It is assumed that the plastic deformation in the zone near the cutting edge has no influence on the springback. It is possible that this influence cannot be neglected. This has to be investigated in the future.

5 ACKNOWLEDGMENTS

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